Development of low cost open-path instrument for monitoring of CO_2 at sequestration sites

Power Energy Environment Research (PEER) Center
CALTECH
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List of commercial open-air gas monitoring instruments

Source	Model Number/Description	**Specifications**	**Approx. Price**	**Comments**
Boreal Laser	Gas Finder	Path Length 1 m to <1000 m good to 1 ppm CO2	$40K	Laser light/reflector Single channel unit
Boreal Laser	Gas FinderMC	Path Length 1 m to <1000 m good to 1 ppm CO2	$150K	Laser light/reflector Up to 8 channels
MSA Instruments	Model 3600 Infrared Gas Monitor	Available ranges 0 to 0.2% CO_2 0 to 1.0% CO_2 0 to 5.0% CO_2	$1605 Note is $4065 for explosion proof	IR detection. Capable of remote sampling from 300 feet
MSA Instruments	Model 3630 Infrared Gas Monitor	Long term stability of +/5% 0 to 0.2% CO_2	$520	IR detection. Designed especially for indoor use. Capable of remote sampling/300 feet
RKI Instruments	Spectralert D/DR InfraRed Gas Detector	CO2 version: 0-2000, 5000, 10,000,50,000 ppm Accuracy +/-2% fsd on all ranges		Remote sensor option up to 50 meters Offshore stainless steel construction.

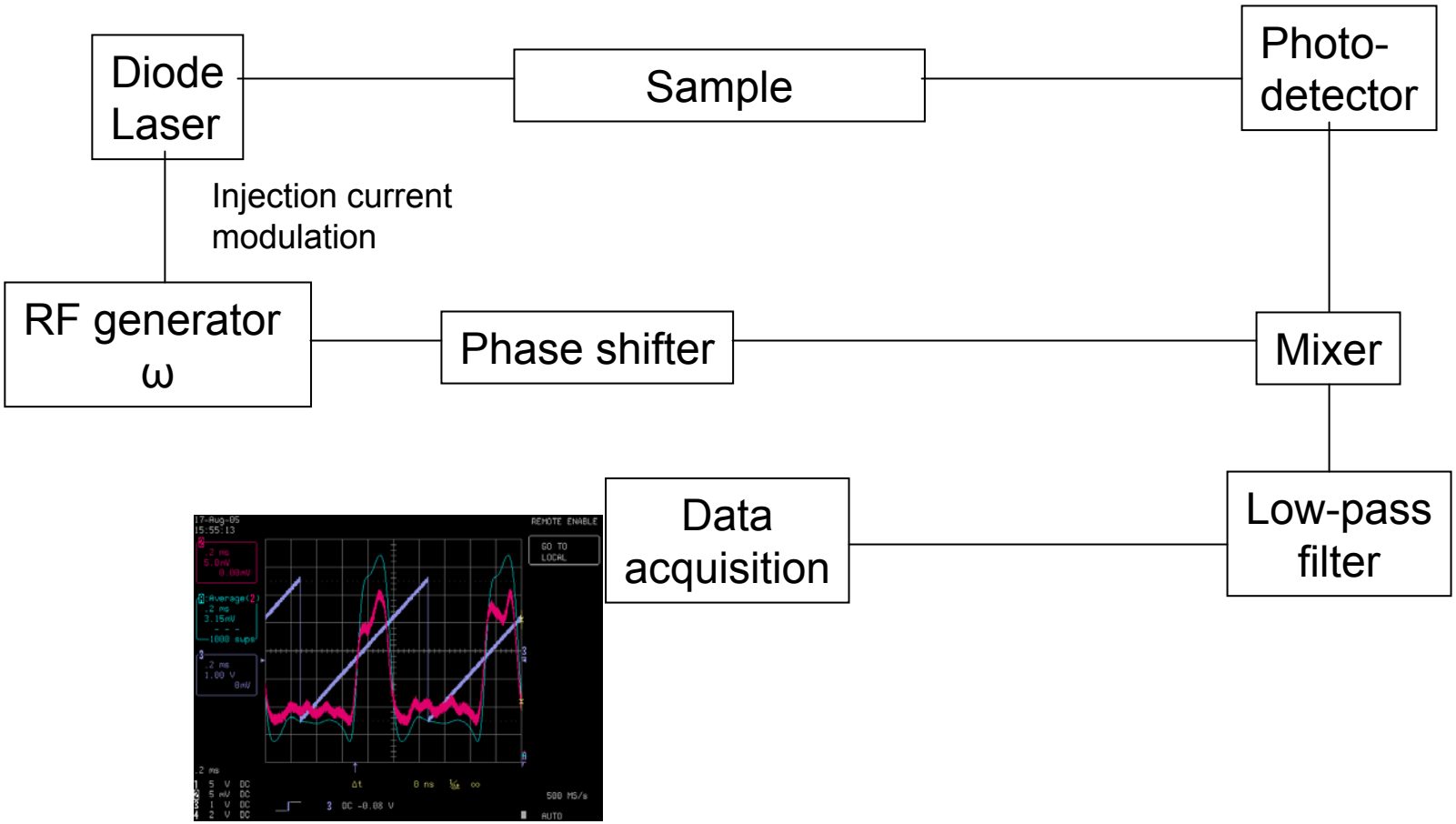
Goals the project

- Extend the monitoring path up to 5 km using commercial low cost telecom amplifiers
- Demonstrate long range (>1 km) open path measurement of CO_2 using FM tunable laser spectrometer
- Demonstrate detection of 1ppmV CO_2 change in the air (nominal ~380ppmV of CO_2 in air)
- Build a field test ready unit

Progress highlights after 6 Quarters

- Finished proof of concept bench top demo in September, 2005
- Tested the bench top instrument in open air over a 100 meters distance in January, 2006
- Built launcher, retroreflector and collection optics for long path (>100 meters) measurements, March, 2006
- Moving towards 1 km test by July, 2006

Frequency modulation spectroscopy (homodyne detection)



Advantages of tunable diode laser frequency modulation spectroscopy (TDL FM)

- Avoids 1/f source noise by shifting detection to frequency ω
- Low cost of diode lasers

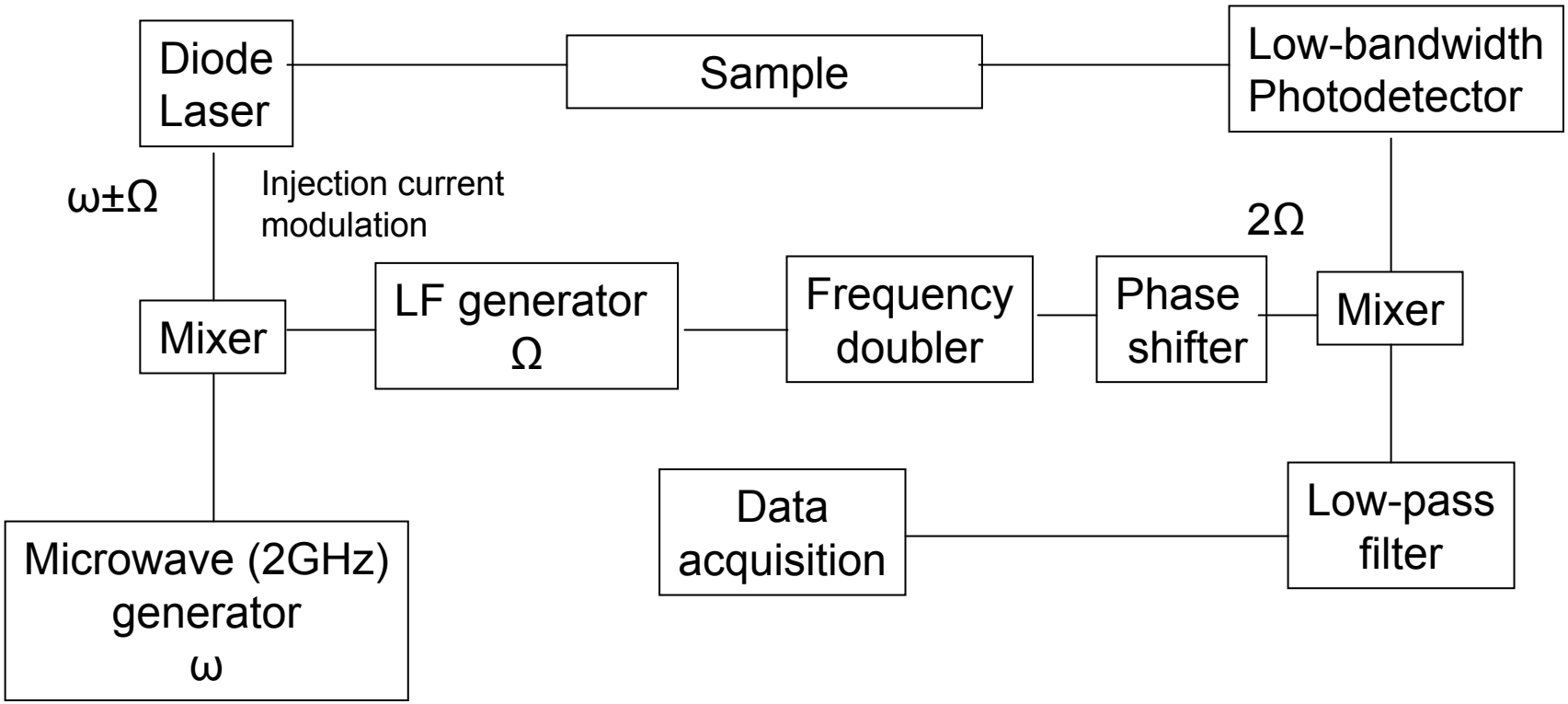
TDL FM spectroscopy at atmospheric pressure

- At the pressure of 1 atm pressure-broadened linewidths (HWHM) are ~0.07-0.1 cm-1 = 2-3 Ghz
- The modulation frequency needs to be comparable with the width of the absorption features

Disadvantages:

- High-bandwidth detectors have small area (smaller than Ø0.3mm) which leads to low collection efficiency
- Requires sophisticated high-bandwidth electronics

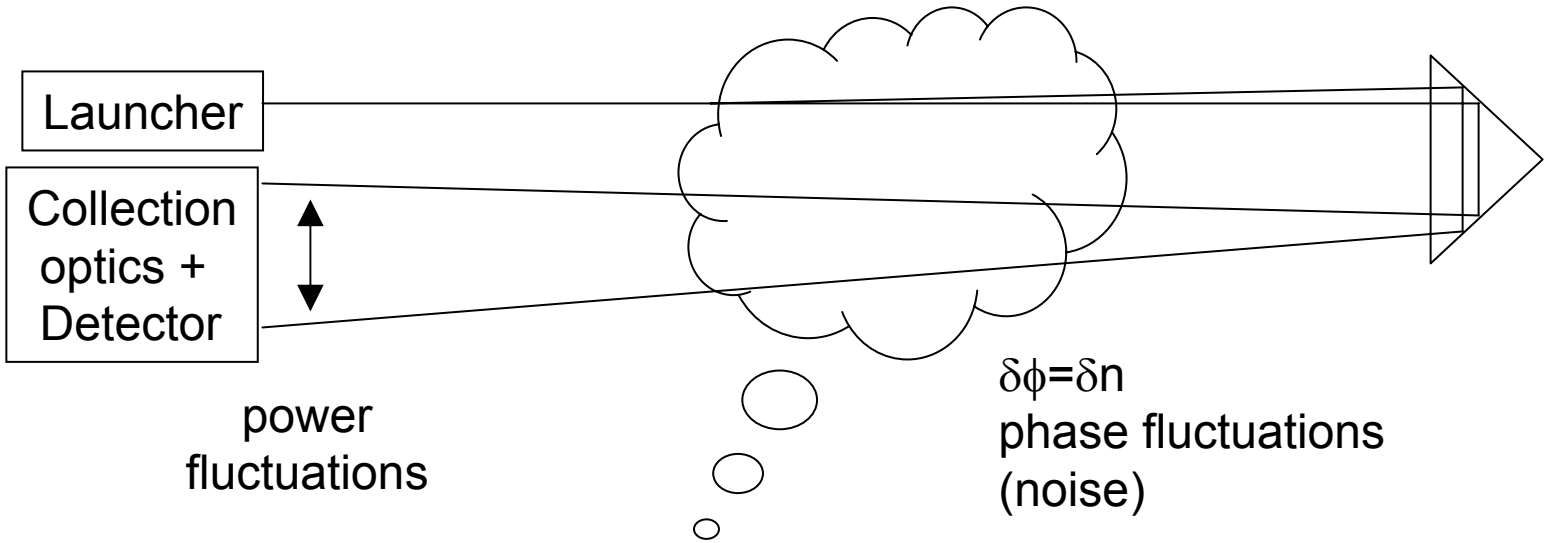
Two-tone frequency modulation



Advantages of Two-tone FM

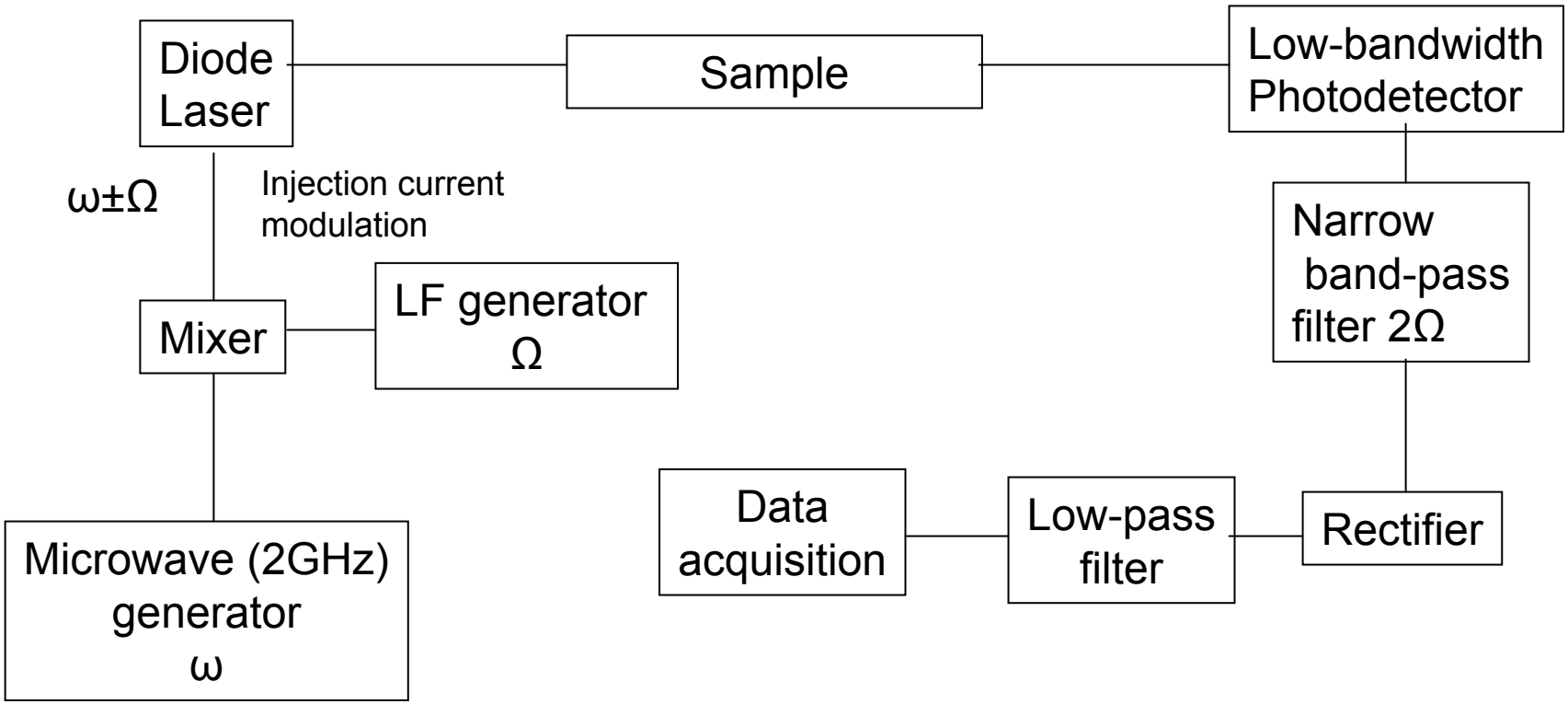
- Utilizes the full width of pressure-broadened rotational lines
- Detection is performed at low-frequency Ω (1-10MHz) permitting to use larger photo detectors and RF amplifiers.

Challenges of open-path detection



- Atmospheric convection leads to power fluctuations and phase noise

Our approach to open-path detection



Benefits of our approach

- Phase insensitive detection --- immune to phase noise introduced by atmospheric convection in the long open path

  A unique design similar to an AM radio --- phase fluctuations on the time scale of kHz is not affecting our measurement.

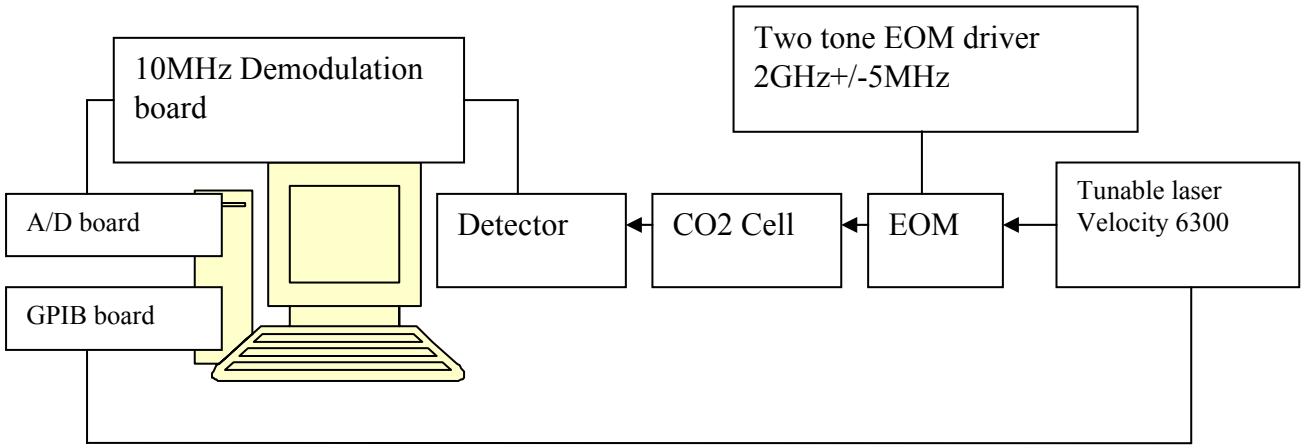
- Two-tone FM detection that features large detector area --- easy to align and capture signal, better stability

Our improvements will make deployment and maintenances very easy and reliable!

Proprietary filing sent to USPTO.

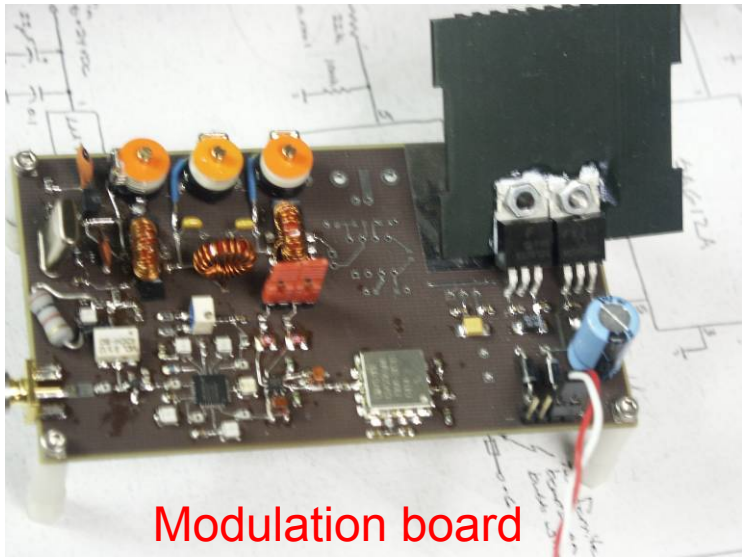
Proof of concept bench top demo

- We designed, implemented and tested electronic circuits for open path FM absorption spectroscopy (TTFM Modulation board, TTFM detection board)

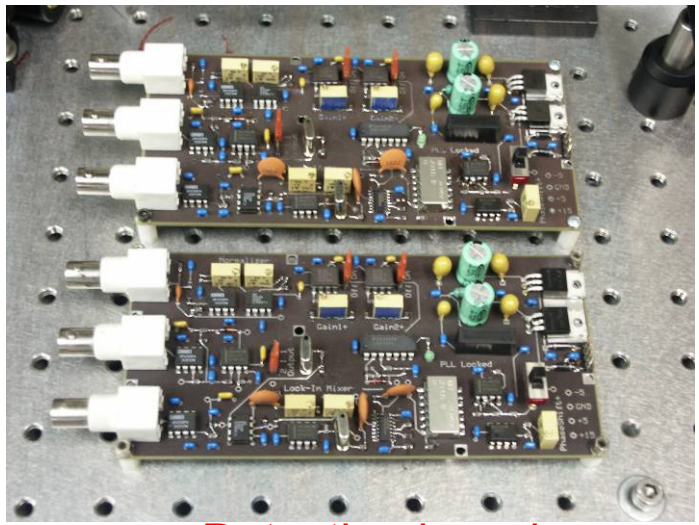


Block diagram of the laboratory setup for demonstration of the viability of the proposed detection method.

Proof of concept bench top demo

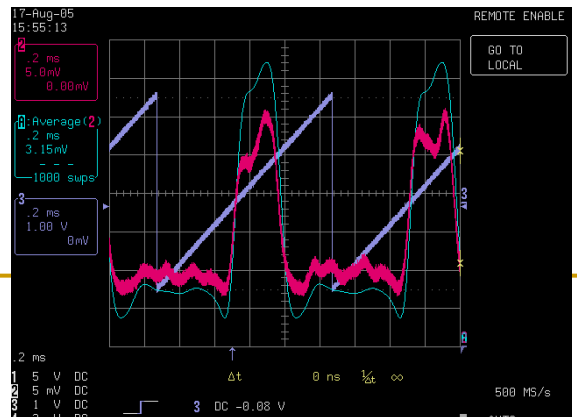


Modulation board

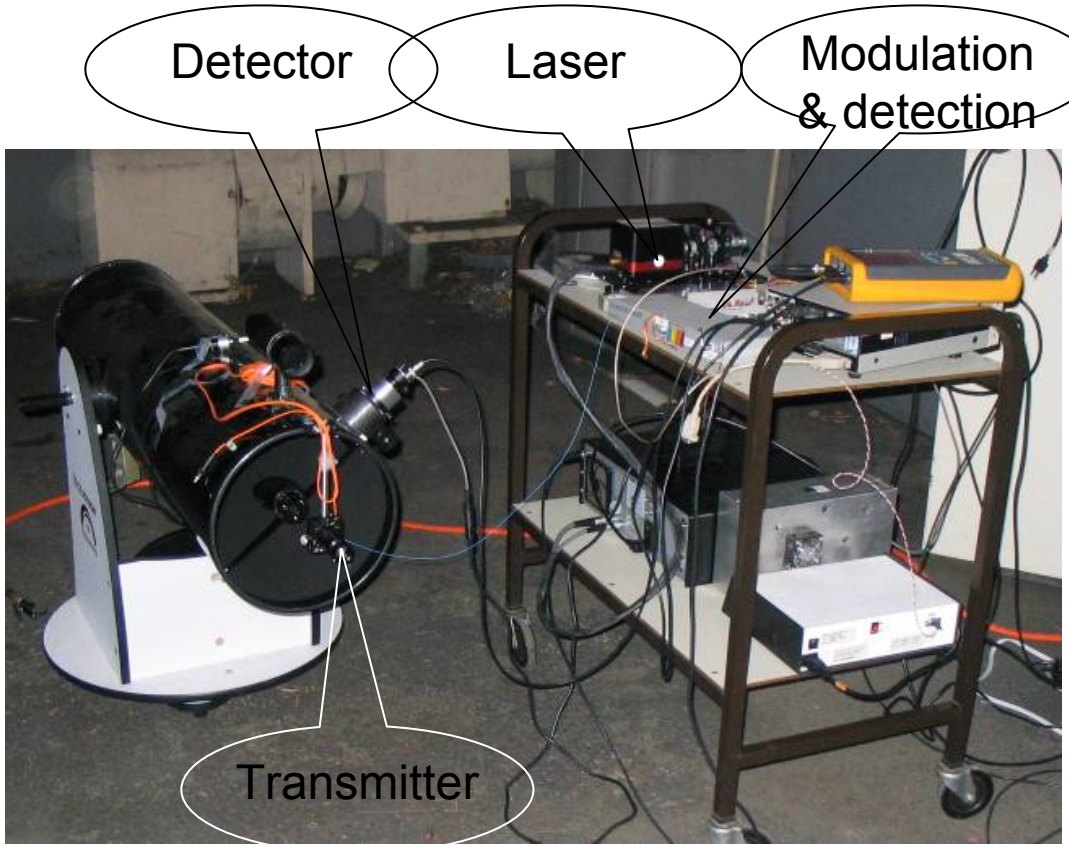


Detection board

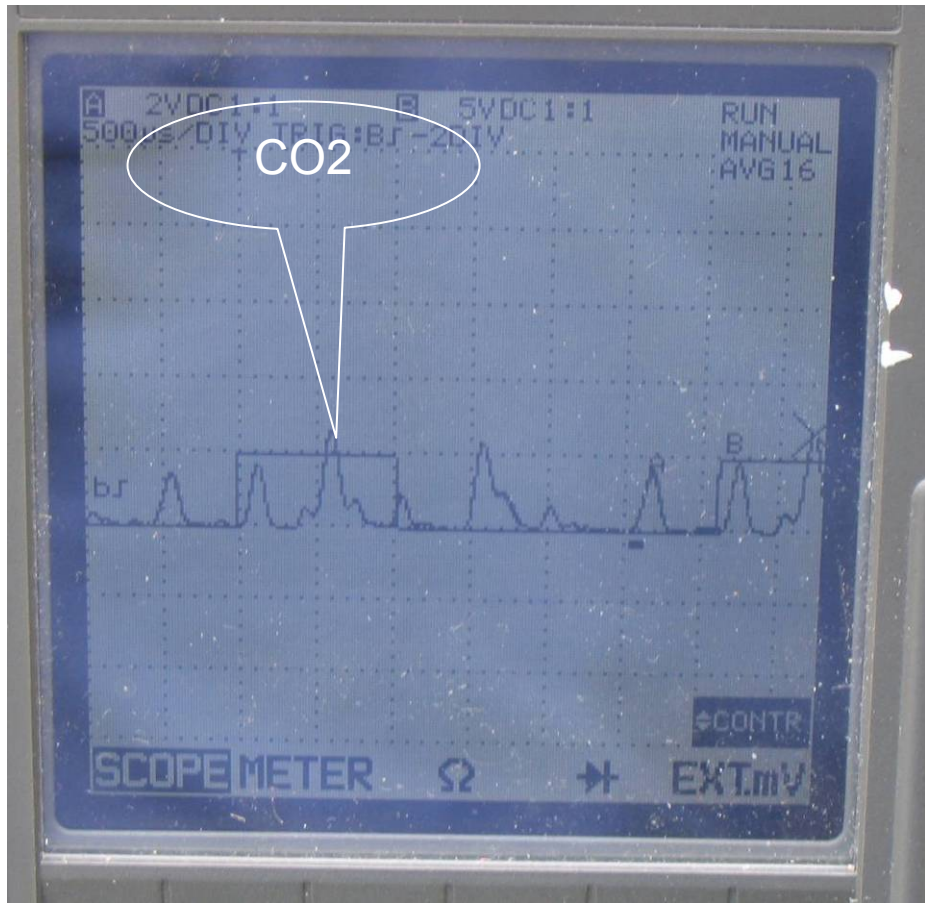
- Demonstrated 10^{-4} signal to noise ratio, 10x better than promised 1ppm CO_2 detectable change in the air



Test of the benchtop prototype over 100 meters

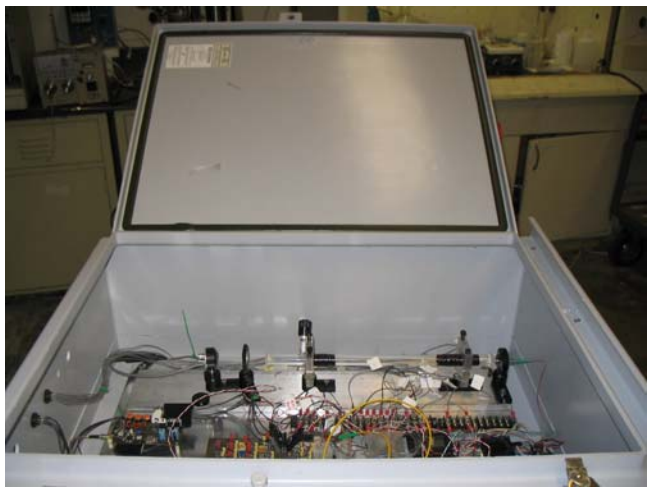


Prototype for field test over 100 meters



Building a field test ready unit

- FM spectrometer and DC power supply are mounted in waterproof enclosures and ready for field tests



Focuses over the next 2 quarters

- Test the instrument with EDFA
- Develop aligning procedure for long distance deployment
- Conduct field tests over a several days time and collect preliminary results
- Characterize the long range capability of this instrument

Acknowledgement

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